

DIRECT UTILIZATION OF THE EYE AS A CAMERA*

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It is generally recognized that Christopher Scheiner, the Jesuit philosopher, was the first to demonstrate the actual formation of an inverted image upon the retina by making a window at the posterior pole of the eye. Although the date of this experiment is generally given as 1619,¹ the date of publication of his *Oculus hoc est*, according to Von Rohr, who has translated Scheiner's works from Latin into German, Scheiner did not report this actual demonstration upon the eyes of animals until publication of his *Rosa Ursina* in 1625.^{2,3} Scheiner's original monographs were unobtainable by the essayist for verification.

The camera obscura had been invented long before Scheiner's investigations and has been credited to Giambattista della Porta (1545-1615), although Leonardo da Vinci and Don Pronrinco⁴ may have antedated Porta, and Polyak finds evidence that its principle was known to the ancient Greeks.⁵ In spite of the obvious comparison of the eye to the camera obscura there was considerable reluctance, both before and after Scheiner's momentous contribution, to accept as a fact the inversion of the retinal image, a premise which had first been evolved upon theoretical grounds by Kepler in 1611.⁶

Prior to Johannes Kepler's monumental contributions as a pioneer in physiologic optics there had been no clear idea of the mechanism of the formation of the retinal image, and, in fact, little advance from the early galenic hypothesis of the

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lens as the receptor of visual impulses. Following the publication of Scheiner's classic experiment numerous investigators corroborated his findings, which have become, especially when performed with an albinotic eye, a standard laboratory demonstration in physiologic optics. In 1638 Rene Descartes removed the posterior wall of the eye and replaced the retina with the flat surface of another object, upon which the image was observed.⁵

Finally in 1877, Kühne,⁷ in carrying out extensive studies on visual purple, produced his famous "optograms," which led to the popular fallacy (still persisting) of the face of the murderer being observed on the retina of the victim. What Kühne did accomplish was to produce an image on the retina by prolonged exposure, light causing a change in the rhodopsin which could be observed grossly for a short time. Using albinotic rabbits, eyes of birds, or, in some cases, eyes with a thin sclera and only moderate choroidal pigmentation, he brought the image (usually a flame, but in some cases a large photographic negative held against the sky) to a focus on the retina as exactly as possible by observation of the sclera (as a ground glass) at the posterior pole of the eye. The animal had first been dark-adapted for 15 minutes, decapitated, and the eye enucleated under a sodium light. After exposure, the duration of which he varied but which usually was for several hours, the eyes were placed in 4 per cent aluminum potassium sulfate solution for 24 hours in the dark. The purpose of the alum solution was to make the subsequent removal and inversion of the retina more readily accomplished and *did not serve to fix the image*, as had been widely misquoted but emphatically denied by the author himself. He was not successful in "fixing" the image chemically in a photographic sense, but after the retina was inverted by punching out the optic nerve and removing the retina under water, he could observe the optogram in the floated retina for as long as 30 minutes and if the retina were then dried in a desiccator the image persisted for a much

longer period. The image of the flame was well reproduced, but more complicated subjects such as the photograph of a man did not show details well.

In 1926 Hidano⁸ photographed for the first time the image formed by the eye. He constructed an apparatus consisting primarily of a metal tube 35 mm. in diameter with a circular opening in the base 12 mm. in diameter. Into this the freshly enucleated eye of a dog was placed with the cornea protruding through the opening. Plaster of paris was placed around the eye to hold it in position and a large window was made at the posterior pole of the eye, removing the sclera, choroid, and retina. Behind the eye was a closed chamber with a piece of glass at the back and an ingenious device connected with a mercury manometer by which the intra-ocular tension could be controlled through use of Ringer's solution in the chamber. The cornea was also protected by a chamber containing Ringer's solution. He found that if the tension were not controlled the globe would collapse and if the cornea were not protected it would become clouded. Using a mirror at a 45-degree angle behind the apparatus and a photographic camera in the proper position, the image formed by the eye was reflected by the mirror into the camera and it was possible to obtain quite clear photographs with a resulting magnification of about three times. These photographs gave no information as to the refraction of the eye, as a clear picture could be obtained whether the image was formed in the vitreous, the normal position of the retina, or even behind the globe. In a subsequent experiment⁹ he inserted a screen in the normal position of the retina, photographing the image on the screen with various lenses placed in front of the eye. A thin layer of paraffin was placed between 2 cover glasses to form this screen, which was arranged so that it could be moved forward or backward by means of a screw. This screen meant that, unlike his first experiments, he was now photographing the image approximately as it would be formed *on the retina*.

Lashley¹⁰ in 1932 photographed the image in albino rats' eyes, the sclera of the undissected eye being used as a screen upon which the image was formed. The eyes were kept in a moist chamber throughout the experiment and it was found that good transparency could be maintained for as long as 30 minutes.

Since the invention and development of the modern camera, with its almost universal use throughout the civilized world and the wide understanding of its general principles, the comparison between the photographic camera and the eye has naturally and repeatedly been made, especially when an effort is made to describe the function of the eye to the general public.¹¹ Verbitzky⁴ has even calibrated the relative apertures of the schematic eye in terms of photographic lenses as $f/4$, $f/6$, and $f/12$, for pupils of 6 mm., 4 mm., and 2 mm., respectively.

In spite of this frequent comparison of the eye to a modern photographic camera and the retina to the sensitized emulsion on the photographic plate or film, a thorough study of the literature does not reveal any evidence that any investigator has ever attempted to *substitute* such film for the retina and thus actually utilize the eye as a camera. While Hidano, Lashley, and possibly others have photographed the retinal image as previously described, they made use of a camera for that purpose and in no case registered the image on sensitized photographic emulsion placed within the eye itself.

In contemplating the possibilities of direct utilization of the eye as a camera certain difficulties are at once suggested. It is self-evident that all media must remain as transparent as possible. Postmortem changes are especially apt to cause corneal clouding, particularly if the epithelium becomes dry for too long a period of time. Reduction of intra-ocular tension incidental to opening the globe may further contribute to loss of transparency. These factors Hidano felt it necessary to overcome to maintain ocular transparency, and to that end he constructed the rather complicated apparatus already

described. Eyes should be used as soon after enucleation as possible and if any appreciable time interval elapses it would seem desirable that precautions be used to keep the tissues as well preserved as possible to avoid more than minimal post-mortem changes. Since the globe must be opened posteriorly to admit the photographic film (which because of its pliability would seem more suitable than a plate) every effort must be made to prevent vitreous loss, and some method would have to be employed to assure that the film was placed in the proper position, comparable to that normally occupied by the retina. Since the image will be small (not enlarged by the process of photography as in Hidano's experiments) it is desirable to utilize a very fine-grain photographic emulsion. Mees¹² has emphasized the fact that since the photographic image consists of grains no matter how sharp the edge of the theoretical image which produced it may be, it will appear more or less ragged under high magnification. The resolving power of an emulsion is the product of 3 factors—graininess, turbidity, and contrast—giving a very complex reaction. Therefore, in spite of using a very fine-grain emulsion it is not to be expected that it will be possible to obtain too clear a positive print if one attempts to enlarge a negative with an image in any way approaching the small size of the macular image. It is consequently to be expected that an area much larger than the macula must be utilized.

With these difficulties anticipated, an attempt was made to substitute photographic film for the retina in the eyes of various animals, and to obtain on that film photographic images by utilizing the eye as a camera. In the series of experiments conducted, the eyes of pigs, sheep, beeves, cats, and rabbits were employed. The first 3 were obtained fresh from the Chicago stockyards, the latter 2 were from laboratory animals, the eyes being enucleated just prior to the experimental procedures. It was found that sheep's eyes were the most satisfactory for this work; they approximate the human eye anatomically (although they are larger in all

dimensions, averaging 28 mm. in length), the media remain clear, and the vitreous is not so fluid as that of rabbits or cats. The beef eyes were too large for satisfactory comparison to the human eye, and the pigs' corneae tend to become clouded as the animals are sprayed with an antiseptic solution before being slaughtered, in accordance with U. S. Government regulations. All eyes from the stockyards were used as soon as possible but there was of necessity an interval of several hours between the time of their removal and their use in the laboratory. Immediately upon receipt from the slaughterhouse they were placed, wrapped as delivered, in a refrigerator with the temperature set at 5° C. With these precautions the media remained grossly quite clear and a very clear view of the fundus could be obtained with the ophthalmoscope.

The first attempts to obtain a photographic image were made by simply placing a strip of unexposed film in front of the retina. Two parallel incisions, about 4 mm. long and about 3 mm. on either side of the estimated position of the macula, were made through the sclera, choroid, and retina. Working in the dark with only a photographic safety lamp, a strip of film 4 mm. wide was placed through one incision, across in front of the retina, and out the other incision. The film was then pressed forward slightly on the lateral side of each incision to make it fit snugly against the retina and conform to its curvature. This was accomplished without appreciable loss of vitreous. The whole posterior segment of the eye was then covered with a dark cloth to eliminate extraneous light and an attempt was made to photograph a visual acuity chart about 17 feet away, using a flashlight bulb. A very fast film, Super XX, was employed. In spite of repeated attempts along this line and the use of various exposure times, no image was obtained on the film. Only a black spot was recorded, showing that the portion of the film within the eye had been exposed to light.

It was realized that in this crude original effort no attempt

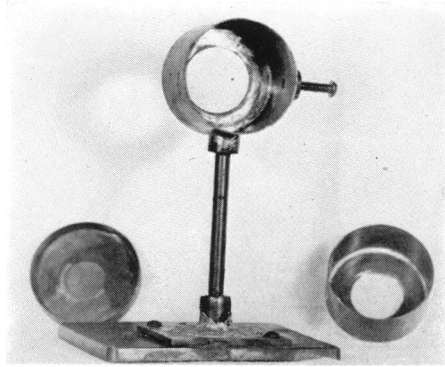


Fig. 1.—Apparatus for holding eye. Shows outer tube mounted in stand (center); inner cup for eye with optical glass in back (lower right); and metal cap (lower left).

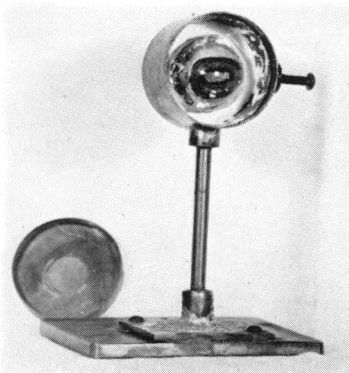


Fig. 2.—Sheep's eye mounted and held by plaster in inner cup, which has been assembled into outer tube. Note set screw at side for keeping position of inner cup firm. Eye ready for use as a camera.

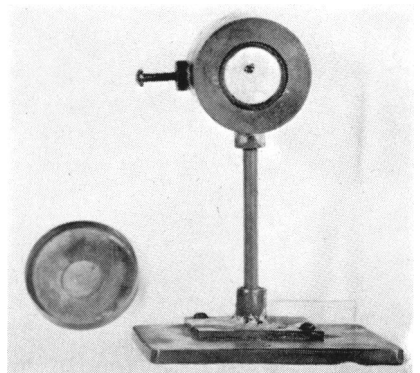


Fig. 3.—View from rear of holder containing sheep's eye, showing window in coats of eye at posterior pole. Sclera fits firmly against optical glass.

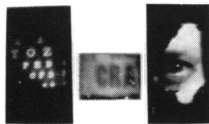


Fig. 4. Fig. 5. Fig. 6.

Fig. 4.—Instantaneous exposure of visual acuity chart negative with transmitted light.

Fig. 5.—Newspaper headline with daylight and 1/50-sec. exposure.

Fig. 6.—Human eye, 60-watt bulb, and 1/10-sec. exposure.

had been made to get the image into focus and that if the eye were other than perfectly emmetropic with relaxed accommodation in this postmortem state one could not hope for a clear retinal (or photographic) image, without the use of a ground glass for focusing.

With the assistance of Mr. Hunter of the Belgard-Spero Optical Company, a metal container was constructed to hold the eye. (See Fig. 1.) This consisted of a piece of brass tubing 26 mm. long and 46 mm. in diameter, the front end open and the back end containing an opening in the brass 23 mm. in diameter, into which was cemented a piece of very thin optical glass, curved as nearly as possible to the posterior conformity of the globe. This inner cup for holding the eye was fitted snugly into a slightly larger piece of brass tubing with an open front and a circular opening in the back 28 mm. in diameter, and mounted on a standard to insure steadiness and ease of handling. A metal cap was made to fit over the back of the outer brass cylinder into which could be placed a metal ring with a central opening, in case it was desired to place the film in position and protect it before being exposed. In practice, however, this cap and ring were not used, as no time was lost between getting the image into focus and then photographing it. Over the front of the outer cylinder could be placed a camera shutter to assist in regulating the time of exposure and if desired, narrowing the size of the effective pupil, which in these animals was usually quite dilated. Such a shutter was used in a number of the experiments performed but in general did not result in much advantage, all exposures being instantaneous. For other types of objects photographed it might, however, offer an advantage.

In preparing the eye for photography, it was first necessary to dissect from the sclera all adherent fat and connective tissue, then a small square window approximately 4 mm. in size was cut at the posterior pole of the eye in the estimated position of the macula, using a cataract knife and sharp

scissors to remove the window of sclera, choroid, and retina. It was found possible to do this without appreciable loss of vitreous or noticeable collapse of the globe. Holding the eye with the window up, the inner brass tubing was then placed over it, so that the window was snugly against the optical glass in the back end. The eye was held in this position while the whole was inverted. In order to hold the eye in the proper position with the window against the optical glass and not permit any loss of vitreous, a quick-setting plaster (Kerr's Snow White Impression Plaster No. 2) was poured around the eye from in front. This held it securely and it was not found that the plaster reached the posterior part in any way to interfere with visualization through the glass and window. Dental cement (S. S. White) was also tried for this purpose; it held the globe securely but became so hard it was difficult to remove, hence its use is not recommended. The inner tube was then mounted in the outer holder, being pushed completely to the back of it so that the center of the optical glass protruded slightly through the opening in the outer cylinder. (See Figs. 2 and 3.) During this process of preparation the media usually remained quite clear and with an ophthalmoscope one could read newspaper print placed against the optical glass. In some cases the cornea was irrigated with normal saline solution at short intervals.

A part of a visual acuity chart had been photographed on a negative which was placed on the front of an ordinary viewing box, giving a constant illumination from behind, with the letters appearing white against a black background. When the eye in its holding apparatus was directed toward this object the letters from this chart were seen sharply and distinctly as inverted letters in the window in the back of the eye. It was noted, however, that this was true for any and all distances at which the eye might be placed from the chart. This was due to the fact that the image was clearly seen by the observer's eye whether it was formed in the vitreous, in the retina, or in the air behind the window. This was demon-

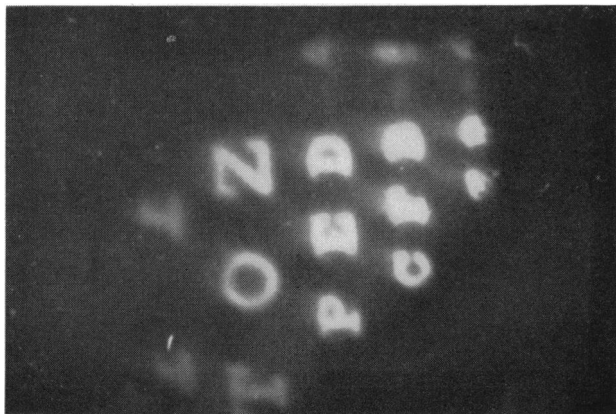


Fig. 7.—This is Fig. 4 enlarged about 7 times.



Fig. 8.—This is Fig. 5 enlarged about 5 times.

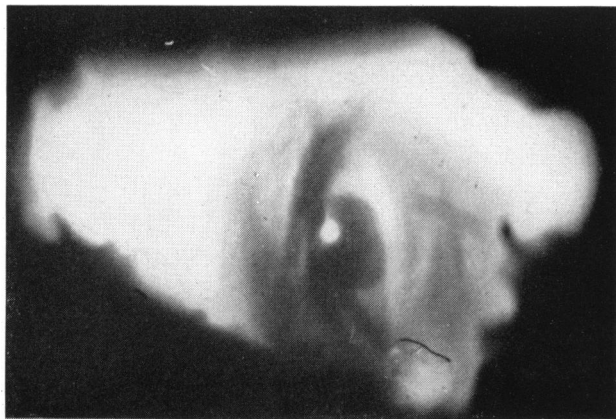


Fig. 9.—This is Fig. 6 enlarged about 6 times.

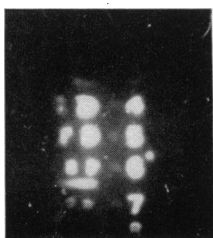


Fig. 10.



Fig. 11.

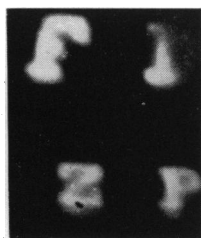


Fig. 12.

Fig. 10.—This is a photograph obtained with a rabbit's eye, enlarged about 4 times.

Figs. 11 and 12.—These are higher magnifications of images obtained with sheep's eyes.

strated by placing a small piece of ground glass against the optical glass. When this was done the letters were visualized on the ground glass *only* when very exact focusing was done by varying the distance of the eye from the object, a very slight increase or decrease of this proper distance for focusing then causing the image to blur and disappear entirely. Many films were exposed with negative results before the need of such precise focusing was realized in practice although it had been anticipated on a theoretical basis. The extremely sharp image seen in the window had been deceptive; thereafter all focusing of the image was done with the ground glass. It was found in all cases that for a sharp focus on the ground glass the distance from the object to the eye must be rather close, as might in part be accounted for from the fact that these animal eyes often showed a slight degree of myopia when viewed with the ophthalmoscope, this being further increased by the fact that the film was of necessity placed slightly behind the normal position of the retina, with the thickness of the choroid, sclera, and optical glass lying in front of the film. Postmortem changes together with lowered intra-ocular tension might also be a factor in accentuating the apparent myopia.

When this apparatus was used, as indicated above, with a small piece of film backed with black photographic paper, held over the optical glass behind the window, satisfactory photographic images were obtained of the visual acuity chart and several other objects as indicated in the illustrations. (See Figs. 4 to 12.) Exposure time could not be measured exactly except in a few cases in which the shutter was employed; in the majority the exposure was instantaneous, the light in the viewing box being snapped rapidly on and off. After the proper position of the eye had been determined by use of the ground glass the film was placed in position in the dark by the sense of touch and exposed and immediately developed.

Every effort was made to keep the cornea clear by keeping

it moistened with normal saline, and fresh eyes were used after every few exposures. However, in one case a satisfactory photograph was made after an eye had been kept overnight in an icebox. In some cases when the eye appeared to be abnormally soft normal salt solution was injected into the vitreous with a hypodermic syringe, to produce an approximately normal intra-ocular tension. No other effort was made to maintain the intra-ocular pressure at a normal range, but especially when sheep's eyes were used the eyes did not appear to develop sufficient hypotension to produce effects deleterious to the object of the experiment.

While the practical importance of utilizing the eye for a camera and obtaining an image which approximately corresponds to the image cast on the retina of the eye in life may not be overwhelming, it does suggest possibilities in physiologic optics, at least in a demonstration of well-known hypotheses. For example, the size of the retinal image in relation to the object and the distance could be well demonstrated, especially with further improvements in technic. Our difficulty in this regard, in spite of repeated attempts, lies in the extremely small size of the retinal image when the object is at any distance, making photography of distant objects almost impossible. Accepting the hypothesis that the smallest resolvable retinal image must have a diameter just greater than a macular cone (about 0.002 mm. according to Schultze,¹³) we must conclude that present photographic emulsions would not permit photographing of an image approaching the minimum visual angle. For practical purposes this is considered to be about one minute although on theoretical grounds it would be less. Adler¹⁴ has called attention to some of the factors which may influence the visual acuity, such as errors of refraction, size of the pupil, intensity of illumination, and use of monochromatic light (experimental). He has also called attention to other factors, such as the aligning power of the retina which is much more sensitive than the resolving power and which, together with physio-

logic influences, may greatly increase the visual acuity. In determining standards of visual acuity the minimal visual angle of 60 seconds has been generally accepted, however, as the normal. In photographing retinal images we can, of course, eliminate all physiologic factors but we must substitute those of a physical or mechanical nature, especially as related to the nature of the photographic emulsion.

The size of the retinal image is dependent upon the visual angle formed by the object and not upon the distance of the object from the eye, so long as the distance is within the limits of accommodation, as emphasized by Southall.¹⁵ Although there is a theoretical difference in the size of an image from an object subtending 1° at the anterior principal point of the eye from the state of full relaxation of accommodation to greatest accommodative effort, this shows a difference in size of the image between 0.293 mm. during relaxation and 0.286 mm. during accommodation, and may therefore be disregarded.

The simplest formula for determining the theoretical size of the retinal image is quoted by Duke-Elder¹ as follows, where AB is the object, ab the image, and N the nodal point of the eye:

$$\begin{aligned} ab:AB &= bN:BN \\ ab &= AB \times bN/BN \\ \text{Since } bN &= 17.054 \text{ mm.} \\ i &= 17.05 \times O/D \end{aligned}$$

where O is the size of the object and D its distance from the nodal point of the eye.

Since the length of the eye will not always conform to the measurements of the schematic eye the image will be slightly larger in an axially myopic eye and smaller in an axially hyperopic eye.

Attempts to prove these relative image sizes were not too successful with the sheep's eye and this photographic method. For example, in a sheep's eye which required a -18.00 diopter lens in the ophthalmoscope to visualize clearly newspaper print held against the optical glass with the eye placed as

described in the holder, indicating an effective myopia of -18.00 D., it was found that the image was brought to a focus on the ground glass when the eye was placed 5.5 cm. from the object to be photographed. When a -13.00 D. lens was placed 1 cm. in front of the cornea the distance from the object to the cornea required to obtain a sharp focus was increased to 18.7 cm., findings quite consistent with the degree of myopia as estimated. Satisfactory exposures of the film were made at these distances. Measurement of the "O" in the "TOZ" on the developed film at the 18.7 cm. distance from object to cornea showed it to measure 0.9398 mm. in its greatest horizontal meridian. Estimating the distance from the object to the nodal point of the eye as 192 mm. and measuring the actual horizontal diameter of the "O" in the object photographed to be 13.43 mm. should, according to the formula for estimating image size, give a resultant image of 1.1873 mm. (instead of the actual 0.9398 mm.). Several other estimations at other distances gave a similar discrepancy with about the same proportionately small size of the actual image than could be theoretically deduced.

As an explanation of this apparent error it should be emphasized that the formula used for computing the image size is based upon the findings for the *human* eye with a nodal point 17.05 mm. in front of the retina. The sheep's eye, being somewhat longer (average 28 mm.) and having a different corneal curvature, will naturally have a different nodal point, the distance of which in front of the retina has apparently never been calibrated. If one could assume the accuracy of the conditions under which the image was formed and photographed to be comparable to that existing in the living eye, it might be possible to deduce from the known formula for image size the position of the nodal point in the sheep's eye. In order for the image formed to measure 0.9398 mm. in the above experiment, with the distance to the cornea 187 mm. (and therefore 215 mm. from the object to the retina or film) one would have to assume that the nodal

point was approximately 14 mm. in front of the retina. This is proved by the formula:

$$\begin{aligned} i &= N \times O/D \\ i &= 14 \times \frac{13.46}{201} \text{ or } 0.9353 \end{aligned}$$

It does not seem reasonable to assume that the nodal point in any eye 28 mm. long lies as far back as 14 mm. in front of the retina and no such claim is made. It would seem probable that the technical difficulties involved, together with post-mortem and intra-ocular tension changes and the myopia noted, account for the apparent error.

Further discrepancies occurred when the eyes used for photography were placed at any great distance from the object, which were incompatible with the degree of refractive error estimated. For example, in one eye with an estimated 18 diopters of myopia (to the film, not to the normal position of the retina) a focus was obtained when the cornea was 5.5 cm. from the object, as would be expected. With a -7.50 sphere placed 2.5 cm. in front of the cornea the distance was 6.5 mm., and with a -13.00 sphere the distance increased to only 11 cm.; with a -17.00 sphere to 12.5 cm., and with a -20.00 D to only 20 cm. The image became so minute at this distance that it was impossible to carry the experiment farther.

It is realized that the images in all these experiments are not macular images only, due to the very obvious impossibility of photographing such minute images by present methods. Further objections may be made to the fact that the position of the film was slightly behind the normal position of the retina. Since no claim is made that the images formed are any indication of the vision obtained by the animal in life (as no consideration is given to the function of the higher visual centers) the fact that much more than the fovea is involved in the formation of these images is not really a valid criticism. The main object has been to demonstrate that the eye can actually be used as a camera, a fact which is of interest

chiefly because of the frequent comparison made between the two. It is conceivable that with future developments in photography it may be possible to demonstrate mathematically the size of retinal images according to the accepted formulae and perhaps to prove experimentally other theories in physiologic optics.

No human eyes were available for this study, but there is no reason to expect any important facts to be demonstrated by their use which cannot be brought out with these animal eyes, with the possible exception of more accurate determination of image size.

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